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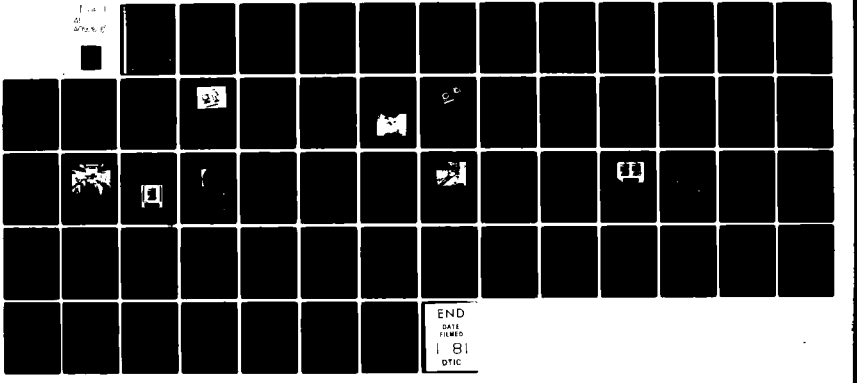

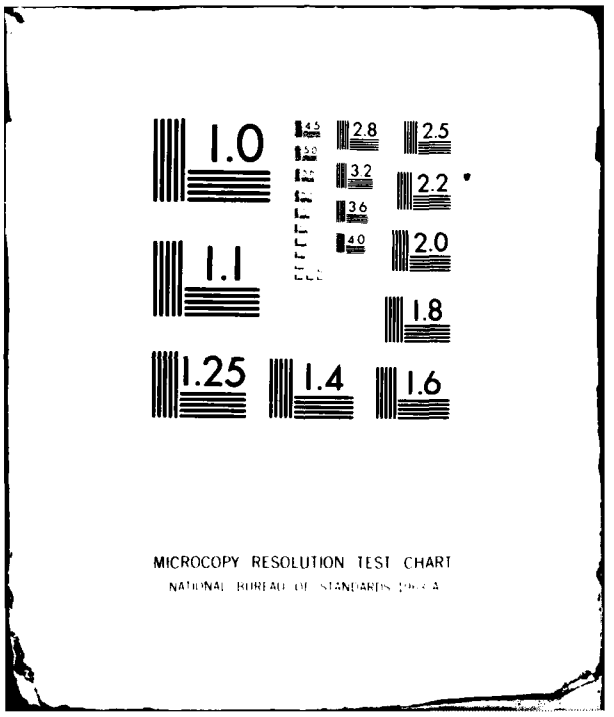
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NATIONAL BUREAU OF STANDARDS

Report No. FR-80-72-1292

TECHNIQUES FOR FABRICATING HIGH RESOLUTION LIQUID CRYSTAL RETICLES

Hughes Aircraft Company
Culver City, California 90230

Contract DAAK-10-78-C-0386

November 1980

Final Technical Report

Prepared for

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The overall objective of this two-phase program was to develop techniques for fabricating high resolution liquid crystal reticles suitable for military application. The first phase of this program consisted of three technology development tasks, namely substrate improvements, liquid crystal seals,

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and electronics seals. The goal of each development task was successfully accomplished. Results are summarized below:

1. Techniques were developed to produce 98 percent working electrode lines without repair (100 percent with repair) on LCR plates with a density of 580 lines per inch. Results were verified by optical inspection and electrical test.

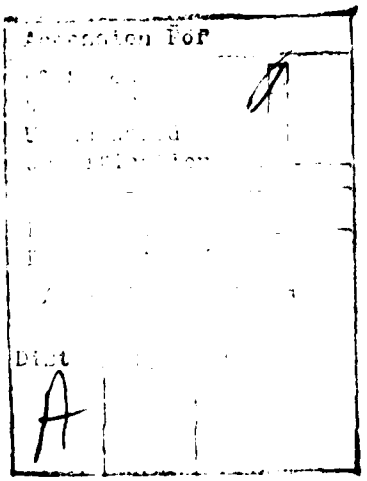
2. LC cells fabricated with Ablefilm 539 sealant have now surpassed 7000 hours at +80°C and -17°C without cell deterioration. Additional cells with bulk electrodes and continuous AC voltage have surpassed 6200 hours at +25°C without alignment change. Other cells fabricated with Ablefilm 539 showed no signs of weakening when exposed to liquid nitrogen or boiling water conditions.

3. A dual coating of silicon nitride and parylene demonstrated moisture protection, but the process was costly to apply and difficult to repair. Conventional hybrid solder sealing technology was used to devise two alternate packaging concepts to maximize producibility and maintainability with potentially lower production costs.

The second phase of this program consisted of designing, fabricating (using the technology and procedures developed under the Phase I program), testing and delivering a liquid crystal reticle.

Under Phase II a two axis reticle configured to have an azimuth and elevation line density of 580 lines per inch was developed. The reticle also contains a four digit range display and displays eight discrete messages. The overall reticle size is approximately 4.5 x 4.5 x 0.5 inches. The visual and electrical testing of the reticle showed 100 percent line yield is achievable.

This program has conclusively demonstrated the feasibility of fabricating functional high resolution liquid crystal reticles.



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PREFACE

Technology development of techniques for fabricating high resolution liquid crystal reticles was conducted by the Hughes Aircraft Company, Culver City, California, from October 1978 through November 1980, under contract DAAK-10-78-C-0386 for the U.S. Army Armament Research and Development Command, Dover, New Jersey. This final technical report describes the results and findings of work undertaken on this contract.

1.0 INTRODUCTION AND SUMMARY

The liquid crystal reticle (LCR) is an electronically-operated digital moving reticle mounted directly into the optical train of a sight. The LCR has many important advantages over state-of-the-art servo-driven opto-mechanical projected reticle. These advantages include:

1. Simple digital design and computer interface
2. Small size and light weight
3. Improved stable boresight and excellent linearity
4. No moving parts resulting in significantly improved reliability
5. Lower acquisition, maintenance and life cycle costs
6. Improved light transmission as beamsplitters are eliminated.

The feasibility of LCRs of lesser resolution have been previously demonstrated with hardware models delivered under a separate Army contract. In addition Hughes successfully integrated this LCR into a widely demonstrated modular fire control system in January 1977.

It was approximately 4.5 x 4.5 x 0.5 inches in size, and fit directly in the optical train of the M32 8X day elbow. The deflection capability as a disturbed reticle is +69 to -17 mils in elevation and ±30 mils in azimuth. The center-to-center spacing of 0.2 artillery mil between lines gives a reticle system. Incorporated into the LCR, in the telescope field-of-view, is an alphanumeric display of laser range, ammunition type, and other discrete symbols. The assembly had 95 percent total working electrode lines in the azimuth and elevation axes (approximately 98 percent working lines per axis).

Results from the previous Army contract proved that LCRs can be made to withstand the armored vehicle environment. In addition, the results also demonstrated:

1. The feasibility of fabricating a prototype LCR with 49 lines for elevation and 299 lines for azimuth
2. Transparent thin film heating that allows operation from -40 to +125°F

3. Shock and vibration mounting schemes for armored vehicle environments
4. New electronic driver schemes with a simple electronic controller
5. Installation and operation on a thermal nightsight, using essentially the same volume as the existing fixed reticle, and with only one reticle line not functional.

The overall objective of the current program was to refine and further the development of techniques for fabricating high resolution liquid crystal reticles suitable for military application with emphasis on tank applications. The program consisted of two phases. Phase I consisted of three technology development tasks and Phase II that consisted of hardware design, development and demonstration. The goals for the Phase I technology development tasks were:

1. *Develop techniques* to achieve 100 percent working electrode lines on LCR plates with a density of 580 lines per inch.
2. Develop a seal for liquid crystal (LC) cells that is chemically compatible with LCR manufacturing.
3. Develop a seal for the electronics required to address and drive individual reticle lines compatible with LCR manufacturing.

Each of the three required development tasks were successfully concluded. The results of which are summarized below:

1. Techniques were developed to produce 98 percent working electrode lines without repair (100 percent with repair) on LCR plates with a density of 580 lines per inch. Results were verified by optical inspection and electrical test.
2. LC cells fabricated with Ablefilm 539 sealant have now surpassed 7000 hours at +80°C and -17°C without cell deterioration. Additional cells with bulk electrodes and continuous AC voltage have surpassed 6200 hours at +25°C without alignment change. Other cells fabricated with Ablefilm 539 showed no signs of weakening when exposed to liquid nitrogen or boiling water conditions.
3. A dual coating of silicon nitride and parylene demonstrated moisture protection, but the process was costly to apply and difficult to repair. Conventional hybrid solder sealing technology was used to devise two alternate packaging concepts to maximize producibility and maintainability with potentially lower production costs.

An interim technical report documenting the techniques developed for fabricating high resolution liquid crystal reticles was prepared and distributed. The report was titled "Techniques for Fabricating High Resolution Liquid Crystal Reticles," Interim Technical Report, and was dated December 1979.

The appendices of this report discusses the results of Phase I.

The goal of Phase II was to incorporate the results of the technology development phase (Phase I) into the fabrication of an advanced exploratory development reticle. In this phase a high resolution reticle was designed, fabricated, assembled and tested. Although the initial intent was to also integrate this reticle into a government furnished sight, scheduling and funding problems precluded this from occurring.

The characteristics of the fabricated reticle are summarized below:

- Two-axis (azimuth and elevation)
- 580 lines per inch density with a maximum of 400 lines in azimuth or elevation
- Four digit range display
- Eight discrete messages
- Reticle size including drive electronics to be approximately 4.5 x 4.5 x 0.5 inches
- 100 percent line yield

The body of this report discusses the results of Phase II and is the final report for work performed under contract DAAK-10-78-C-0386.

2.0 LIQUID CRYSTAL RETICLE HARDWARE FABRICATION

Techniques developed from all the previous liquid crystal reticle programs were used to fabricate the LCR substrate assembly. The integrated LCR assembly was structurally bonded to form a monolithic type unit proven capable of retaining alignment during high shock, vibration, and thermal exposures. The basic LCR substrate consists of two glass plates on which the reticle and interconnecting lines were deposited and etched. The plates were structurally bonded together with a thin adhesive film acting as a spacer and barrier around the central active liquid crystal region. After sealing this active area, a thin film heater was incorporated. Later, a number of stainless steel brackets and pads were accurately bonded in place to provide the interfaces necessary for mounting the completed LCR assembly into the unit housing with mounting connectors and covers. These stainless steel parts closely match the thermal characteristics of the glass substrate. This technique was used to avoid putting holes into the glass substrates that might cause stress propagating cracks.

After these bonding operations, the substrate chips were installed and interconnected. All the interconnections from the substrate are terminated to a printed circuit type elastomate connector (Ampliflex) and a wiring board and are then routed to an external connector housing. Glass multi-terminal headers are bonded in place inside this connector housing. The assembly is wired and mounted onto the LCR housing, providing a sealed cable junction for the terminating electrical cable.

The base LCR substrate was designed to provide a compact configuration that could be integrated into the TTS sight. Tradeoff studies were made to determine the best possible form factor of the substrate and the most efficient arrangement of the logic chips and connectors. The resulting design of the substrate was simple to fabricate. The thickness of the glass could be reduced from 0.25 to 0.125 inch, making an even more compact module; however, past tests and analyses were based on the thicker substrate, so there was no change at this time without additional backup data.

The etched logic pad clusters on the substrate were configured to permit the easy removal and replacement of defective electronic driver chips without damaging the interconnecting circuitry.

Plastic covers were designed to provide electronic driver chip protection. They are held in place by screws, into metal frames, which are side bonded on the glass substrates.

2.1 LCR SUBSTRATE FABRICATION

The substrates are fabricated according to the flow chart shown in Figure 1.

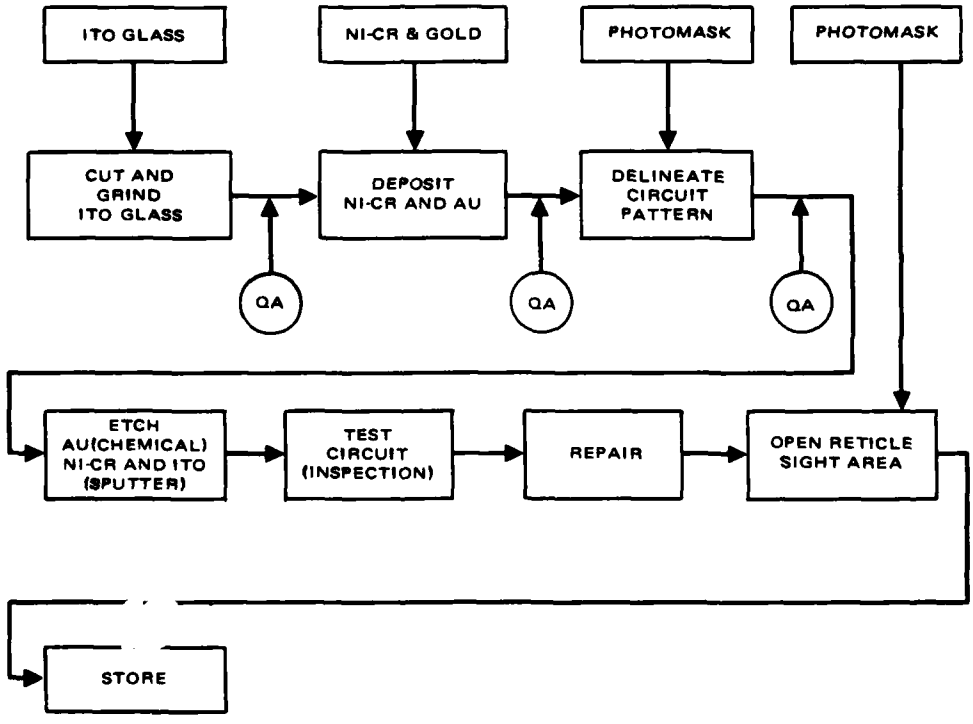


Figure 1. Process flow chart for LCR substrate preparation.

2.1.1 Cutting and Grinding ITO Glass

Transparent conductive glass (indium tin oxide (ITO) coated on one side of soda lime glass), 11 x 16 inches and 1/4 inch thick, was cut and ground into the specified dimensions. Its conductivity was 10 to 30 ohms per square.

The stock sheet was scribed and broken into a rectangular shape of slightly over-sized proportions. Caution was used in preventing the scratching of the conductive coating by flaked-off glass chips. The cut sheets were waxed together into a block and ground to the specified dimensions. Since the dimensions of the finished substrates were irregular, it was important to orient the conductive side in the correct direction; otherwise, the substrates would be a mirror image and useless. Several substrate sheets were oriented in the wrong direction and had to be rejected. This problem can be eliminated if one can design substrates in regular shapes for future production models.

The ground substrates were dewaxed, cleaned, and inspected under a microscope for pin holes and scratches. These defects in the reticle sight area are critical. Acceptable substrates were cleaned by vapor greasing in TCE and isopropanol for metallization.

2.1.2 Metallization

The ITO coated side was coated with 150 Å Ni-Cr and 5000 Å of gold by an Airco E-beam evaporation system in a vacuum deposition. The gold layer was needed to provide better electrical interconnections and to enable bonding to the electronic driver chips. The thin Ni-Cr layer was to provide gold adhesion to the ITO layer. The substrates were kept in circular motion during the deposition for a uniform coating. They were preheated to 125°C before metallization. The adhesion of the metal film was checked using the Scotch tape test and the wire bondability checked by wire bonding 1 mil. Al wire loops. Pull strengths of greater than 6 grams was considered acceptable.

2.1.3 Circuit Delineation

The substrate was then placed on a photoresist spin coater chuck and rinsed with isopropanol while it was spinning. After this cleaning, Shipley positive resist AZ 1350B was dispensed on the cleaned substrate after filtering through a one micron filter paper (this was accomplished by squeezing photoresist through a filter syringe containing filter paper). When the substrate surface was nearly covered by the resist, it was spin-coated at 2500 rpm. An excessive build-up of photoresist occurred around the substrate perimeter of the elevation plates. Considerable time and effort was expended to solve this problem.

The coated substrate was soft baked at 80°C for 30 minutes before exposure using the supplied chrome mask to obtain the required delineation. The mask surface nearest the light source was flooded continually with dry nitrogen during exposure to prevent dust particles from settling on the mask and imposing defects onto the final pattern.

The exposed resist was developed with 50 percent AZ developer in a DI water solution for about 60 seconds while spinning the substrate on the photoresist spinner. It was then rinsed with DI water for 60 seconds and spun dry. The delineated substrate was hard-baked in air at 100°C for 30 minutes and the line quality inspected with a microscope. The photoresist patterns with poor line yield were stripped-off and reworked. Only those with a high line yield were etched.

Very poor line yield was experienced. This was partially due to the complexity of the new circuit design and was compounded by poor quality control of the laboratory environment.

Finally, the circuit delineation was carried out at the Malibu Research Lab by Dr. Hugh Garvin using the same procedure developed during Phase I of this contract in 1979. His result, although not 100 percent perfect, was much more acceptable for LCR fabrications. Environmental cleanliness is absolutely essential when high resolution, high line density of this type is required.

2.1.4 Etching (Chemical and Sputtering)

The substrates with a reasonably good line yield were etched.

A combination of wet chemical etching with RF sputtering etching was employed. Gold was etched with a gold etchant, which is a KI_3 solution. The gold layer showed very little undercutting. The gold etched substrates were rinsed with DI water and blown dry with nitrogen gas. They were then prebaked to eliminate possible bubble forming in the photoresist during the subsequent sputter etching of Ni-Cr and ITO.

For sputter etching, the bottom side of the substrates was greased (Apiezon M) to facilitate heat transfer and attached to the anode. The substrates were then sputter etched in a RF sputter machine with low pressure argon. Since Ni-Cr (150 Å) and ITO (300 to 400 Å) layers were relatively thin, they were sputter etched off in a short time, faster than the masking layer which was also rather thin. After etching, the grease was removed with TCE and the remaining photoresist stripped off with acetone.

Chemical etching of ITO was avoided because of the undercutting problem. ITO etched very rapidly with hot (55°C) 17 percent HCl and it was difficult to stop at the end point without undercutting.

2.1.5 Electrical Check

The etched substrates were checked with a Rucker & Kolls' probe test card for shorts and opens in the circuit interconnects. A special test box with liquid crystal display indicators was constructed.

The test box was found to be unsuitable for the electrical checks, because the fine one mil lines had too high an impedance to give a true reading. It was modified so that a Triplet ohmmeter could be used to conduct the desired test. The defective lines were recorded for the subsequent repair work.

2.1.6 Repair of Defective Lines

Substrate repair was considered an important aspect and cost effective approach in future LCR production runs. During the development work in Phase I of this contract in 1979, it was found that a "masksaver" station was

a versatile and viable tool to open shorts. The masksaver uses a Xenon laser and is manufactured by Florod Corp. It can be fine focused, and the beam size adjusted to match the defect configurations. This laser repair technique was employed in the past to produce 100 percent line yield substrates from those with some defects.

A better repair technique was developed during the current activities. In the repair process, the defective spots must be located by microscopic inspection. The electrical test identifies only the defective lines, not spots. Since the defective spots must be located during the visual inspection, it will save time to incorporate repair work in the inspection step.

This was accomplished by coating the defective substrate with AZ 1350B photoresist before inspection. The inspection of the coated substrate was conducted on a microscope with a red filter. When a defective spot was found, the spot was exposed to the intense microscope light by removing the red filter. The exposure light beam was condensed to the size of the defect spot. After exposing every defective spot the photoresist was developed as in the ordinary delineation process to expose the shorted spots and etched either chemically or by sputtering (subtractive method). This same technique was used to repair opens. In this case, the developed defective spots were sputter deposited with ITO or other suitable metal (additive method). Substrates with open spots were rarely encountered.

2.1.7 Open Reticle Sight Area

The substrates, after the repair cycles, had 100 percent working lines. They were again coated with photoresist and exposed to a mask to etch off gold in the reticle sight area which is approximately a 1.2 inch circle. Since the resolution of this circle is not a critical issue, AZ 1350J, a higher viscosity photoresist, may be employed. The gold was etched by the same chemical method used in the photolithographic delineation of the circuit pattern. The finished substrates were stored for the subsequent LCR assembly operations. A finished azimuth and elevation plates are shown in Figure 2.

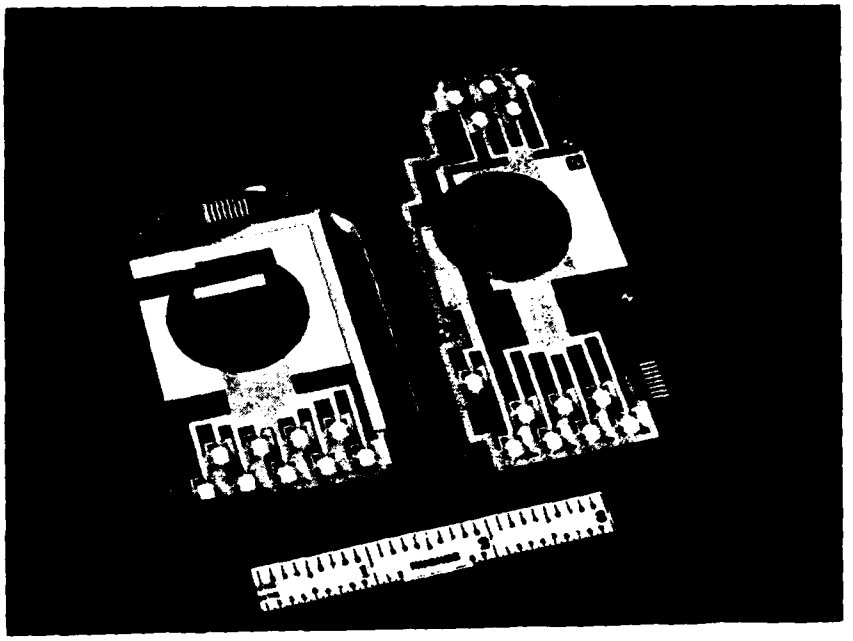


Figure 2. LCR substrates – azimuth and elevation plates.

2.2 LCR ASSEMBLY

The procedures for assembling LCRs are given in the flow chart in Figure 3. Each step is now discussed in detail.

2.2.1 Substrate Cleaning

Cleaning is a very important step and must be handled with great care. The substrates, both azimuth and elevation, were not touched with bare hands to avoid contamination by finger grease.

Reticle substrates were placed in a specially constructed Teflon rack and rinsed with acetone and chloroform. They were then ultrasonically cleaned in acetone and chloroform consecutively for five minutes each. The substrates were rinsed again with chloroform and vapor dried in an isopropanol vapor degreaser.

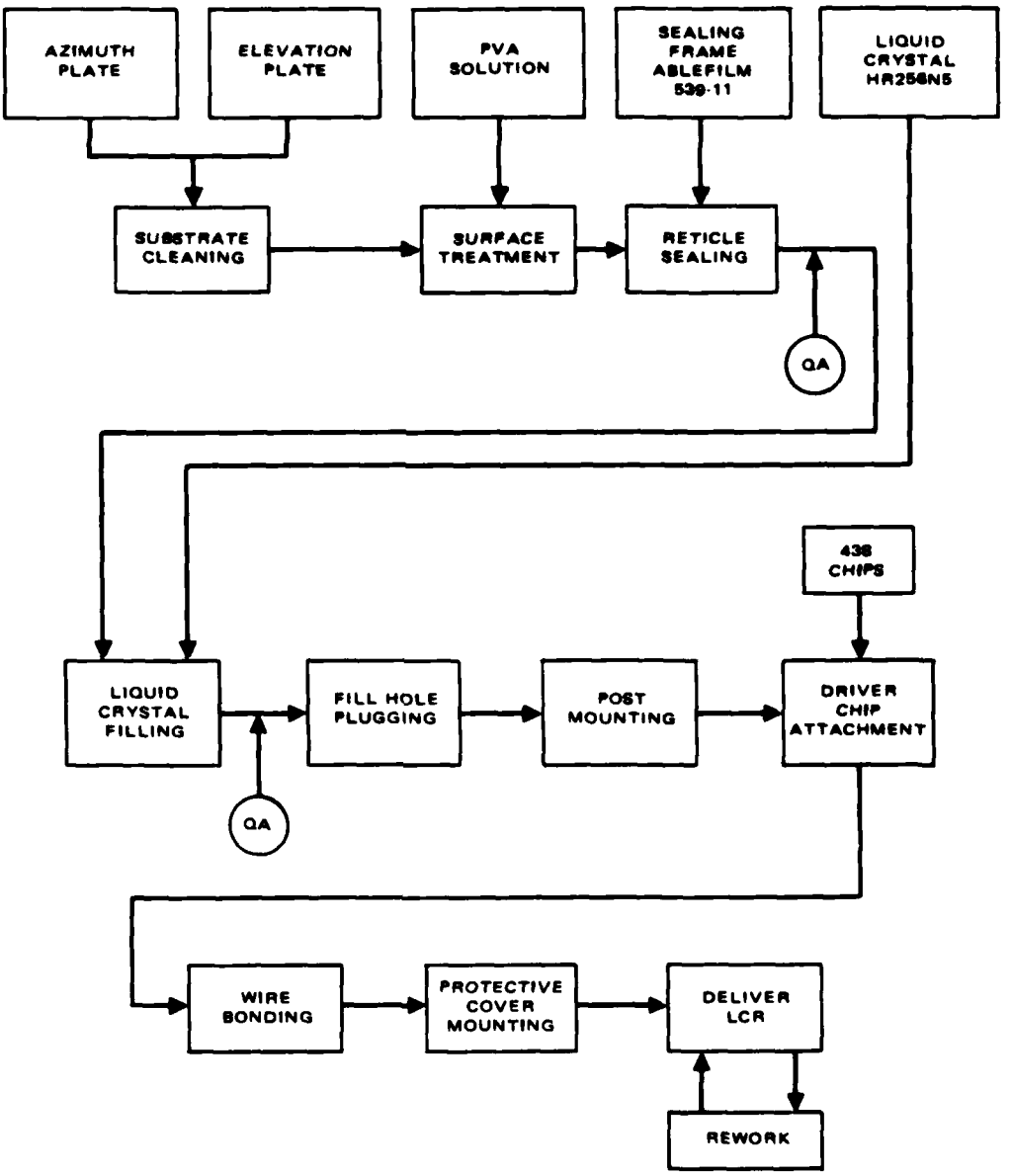


Figure 3. LCR assembly flow chart.

2.2.2 Surface Treatment

Cleaned substrates were placed on a photoresist spinner and rinsed with DI water while spinning at 2000 rpm for 60 seconds. They were then coated with a mixture made of three parts DI water and one part SA-72 and spun at 2000 rpm for 60 seconds. This surface alignment agent is used for AC driving LCR only. The substrates were backed at 110°C for two hours (one hour minimum) in a clean oven. They were then rubbed with Kaydry wrapped around a microscope slide. Each substrate was rubbed five times along the reticle lines with light to medium pressure. The rubbing was in a uniform continuous motion over the reticle sight area with parallel strokes. The rubbing was to align the liquid molecules parallel to the substrate surface. Since the rubbing was parallel to the reticle lines, molecules on the azimuth plate and those on the elevation plate would be oriented 90 degrees to each other (90 degree twisted) in the final assembled LCRs.

2.2.3 Reticle Sealing

Ablefilm 539 Type II (0.5 mil Mylar base) was used for sealing. The film was cut into the desired shape as in Figure 4. The "break water" channel was to protect the reticle sight area from invasion of the fill hole sealant. The preform was placed on the azimuth plate with the fill opening

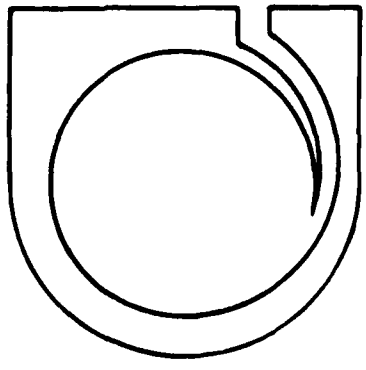


Figure 4. LCR perimeter sealing frame configuration.

positioned for convenient filling later. The elevation plate was then put in place and registration insured using the three alignment targets. The assembled LCR was clamped in the specially designed fixture (Figure 5) and placed in clean oven at 130°C for two hours for sealing. The sealed LCR was inspected for integrity. The perimeters (except the filling edge) of the sealed LCR were reinforced with five minute epoxy and cured. The LCR was ready for filling with liquid crystal. The sealed LCR is compared with the earlier one in Figure 6.

2.2.4 Liquid Crystal Fill

The filling scheme was modified because of the new design configuration (see Figure 6) which made it impossible to use the old filling method.

The old filling procedure was as follows:

A small boat containing liquid crystal and sealed LCR were placed in a vacuum bell jar with the LCR hanging with the fill hole just above the liquid crystal surface in the boat. After thorough evacuation to about 200 microns,

Figure 5. Fixture for assembling LCR.

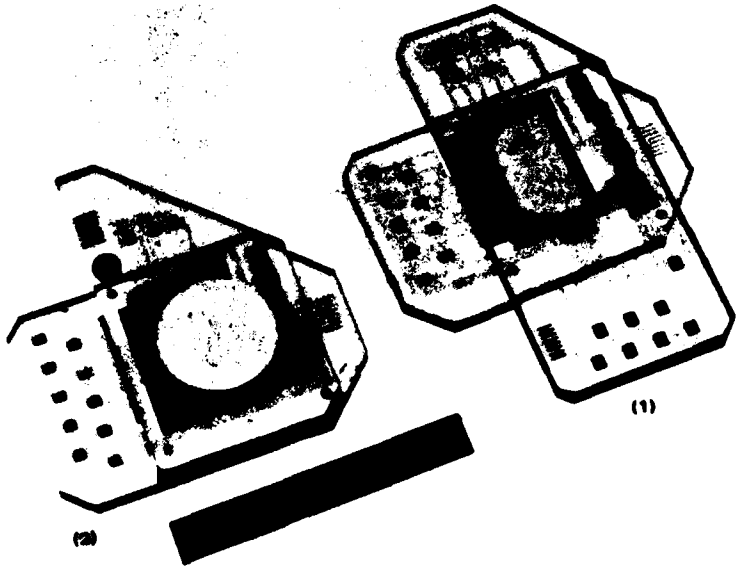


Figure 6. Comparison of new and old LCR designs.
(1) New ARRADCOM design
(2) Old NV & EOL design.

the fill hole was submerged in the liquid crystal to allow LC to enter the fill hole by slowly releasing vacuum.

If the conventional filling method is to be used, the current LCR assembly requires a large quantity of liquid crystal and a large and deep boat. As an alternate, liquid crystal was introduced to LCR instead of vice versa. To accomplish this, two drops of five minute epoxy were placed on both sides of the filling hole to dam and confine liquid crystal in the filling hole area.

The sealed LCR was placed in vacuum bell jar with filling hole facing upward. After evacuation to 200 microns, liquid crystal was introduced through a stop cock and capillary tube placed directly above the filling hole. The LC was dropped on the filling hole and vacuum released slowly to fill the LCR. The liquid crystal used was LC-R-11 which was a Hughes' proprietary HRL-256N5 doped with 0.1 percent TBAB.

2.2.5 Fill Hole Plugging

The filled cell was removed from the filling bell jar. Excess LC was removed from the fill hole. The fill hole was then plugged with Ablestik 224-1, a single component sealant, which does not attack the LC system, and left to cure at room temperature. It cured completely in two hours.

2.2.6 Cover Post Mounting

The completely filled and sealed LCR was then delivered for mounting posts which were to be used for anchoring protective covers. This cover is to shield driver chips and wire bonds from the mechanical damage during the assembly of LCR into the fire control housing.

2.2.7 Driver Chip Attachment and Wire Bonding

Driver chips were prescreened in the test station specially designed and fabricated for this purpose. The chips were attached to the LCR with conductive epoxy and cured at a temperature below 80°C. The chips were then wire bonded to the LCR pads with one mil gold or aluminum wires.

2.2.8 Protective Cover Attachment

The mechanical protective covers were placed on the LCR. These protective covers are designed to prevent damage to the driver chips or their interconnecting wire bonded leads.

2.3 PROBLEMS ENCOUNTERED

The problems which caused difficulties in fabricating and delivering LCRs are summarized below.

2.3.1 Photomask Delivery

Design of circuit layouts for LCR substrates and procurement of photomasks for delineating the circuit on glass substrates combined to result in a mask delivery delay of nearly three months.

The first problem was experienced in the Hughes' CAD area to produce a 10X master. The computer did not have adequate memory storage capacity to produce the master. The design was subsequently split into two sections, which caused Optronics, the mask vendor, to have problems in producing 1X working chrome masks. Film stability made it impossible to join the two masters into a single pattern. Optronics was the most satisfactory vendor in the past, but the first mask delivered had a defective spot. This added an extra two weeks in delay.

2.3.2 Substrate Design

The change in design caused most of the difficulties in the fabrication of glass substrates. The substrate design for the ARRADCOM's LCR (New Design) and that of NVEOL's are compared in Table I.

The substrate size for the azimuth plate is identical for both designs. The number of lines on the ARRADCOM azimuth plate is less by 32 lines and it is more favorable for production.

TABLE I. COMPARISON OF SUBSTRATE DESIGN FOR ARRADCOM WITH THAT OF NVEOL

	NVEOL (Old)	ARRADCOM (New)
Substrate Size		
Azimuth Plate	3.35 x 2.20 inches	3.35 x 2.20 inches
Elevation Plate	3.45 x 1.93 inches	4.4 x 1.93 inches
No. of Lines		
Azimuth Plate	320	288
Elevation Plate	96	384
Line Width	1.2 mil	1.0 mil
Line Spacing	0.53 mil	1.0 mil
Center to Center	1.73 mil	2.0 mil

The elevation plate for ARRADCOM's LCR is approximately one inch longer than the NVEOL's. The lines are nearly one inch longer than those on the old design and there are four times more lines. It is much more difficult to obtain a high line yield for the new design because of increased number of lines. Besides the increase in the number of lines and the line length, the increased length to width ratio of the substrate produced unexpected problems. The higher ratio increased the photoresist build-up near the short edges of the substrate during photoresist spin coating. This problem was eliminated by adjusting the photoresist viscosity and controlling the acceleration rate and spin speed of the photoresist spinner.

The line width and spacing were 1.2 mil and 0.53 mil respectively in the old design. The new design has 1 mil in width and spacing. This spacing is almost twice as wide, which considerably reduces the probability of a short. This was an improvement and made fabrication easier. However, the line length should be shortened for easier substrate fabrication and increased yield. Lines with extra length increases the probability for defects. Die attachment pads could be modified to accommodate chip carriers and thus eliminate the rework problems.

2.3.3 LCR Design

The NVEOL's LCR was designed for DC driving while ARRADCOM's was designed for AC driving. No fabrication problem was expected from the difference. Both driving schemes use almost identical liquid crystal compositions; the only difference is in the dopant.

The same surface alignment method was used for both DC and AC driving; parallel alignment. However, a surface alignment agent such as polyvinyl alcohol could be employed for AC driving whereas the DC driving used no alignment agent. The alignment agent will improve liquid crystal molecular alignment and alignment stability. The service life for the AC driven LCR, should be much longer. The use of AC driving has no negative factors but rather positive ones.

2.4 CONCLUSIONS AND RECOMMENDATIONS

Early difficulties in photomask delivery, photoresist coating, and inadequate cleanliness of processing lab caused some delay in the LCR fabrication, but the technology to produce a LCR of the current design exists. A good clean room of 100 class is essential for the production process. The next generation LCR may be improved for higher yield production by reducing extra length in the interconnects.

3.0 RETROFIT OF THE TTS DAYSIGHT WITH A LIQUID CRYSTAL RETICLE

3.1 MECHANICAL DESIGN AIMS AND OBJECTIVES

To design and fabricate a prototype liquid crystal reticle, (LCR), assembly and retrofit it into a TTS daysight. The complete assembly would fit in the available area that encompasses the focal plane. The removable daysight would be reworked to allow the installation of the LCR assembly.

It was our goal that the rework to the daysight should not preclude its return to the original basic configuration.

3.2 MECHANICAL DESIGN

The LCR housing is composed of three sections:

1. A basic housing to support the LCR substrate assembly, and provide the piston seal interface to the TTS unit.
2. A cover plate which forms the sealed area for the LCR substrate assembly and supports the modified eyepiece.
3. A small cover which encloses the area for terminating the external interconnection wires.

The LCR housing was developed to retain the basic mounting hole patterns and features of the existing sight, with only the eyepiece area moderately changed. It provides the mounting features to accurately locate and retain the LCR substrate assembly to the optical axis of the sight.

The basic optical design was kept intact. This required an optical correction in the location of the focal plane, due to the added glass path of the LCR substrates. These corrections were calculated and incorporated into the housing and cover design.

Because of the many new interface problems in changing the existing TTS housing and harness, all the LCR electrical connections are made through a sealed header in the new housing. The wiring connections therefore are external. The internal termination of the connections however, would be preferred on future development programs for reduced cost and improved unit appearance.

The front cover area of the TTS daysight elbow assembly was reworked as follows.

The azimuth and elevation adjusting knobs and their associated mechanisms were removed. The holes left for these devices were filled with special O-ring sealing plugs.

The eyepiece support area was machined flush with the raised portion of the front cover. Four holes were drilled and threaded, in line with the removed eyepiece attaching holes. These threads are used to attach the new LCR housing. The hole for the optical path was opened to 1.50 diameter. This will provide the piston O-ring seal at the new housing interface.

The eyepiece was disassembled and modified as follows. The mounting flange was machined off and replaced by a 2.00-32 thread. This thread will screw into the new reticle housing cover.

The lens cell was shortened and a new O-ring groove added. This will allow the maximum forward travel of the inner lens cell assembly during the negative diopter adjustment. Due to the fixed front focal length of the existing eyepiece, and the added 0.25 inch thickness of the elevation reticle plate, the forward movement of the lens cell is physically restricted by approximately two negative diopters.

APPENDIX A
SUBSTRATE DEVELOPMENT TASK

A.1 AIMS AND OBJECTIVES

The overall objective of this task was to achieve 100 percent working electrode lines on liquid crystal reticle glass substrate plates. Fabrication of defect-free electrode lines, with an approximate density of 580 lines per inch, required that a technique be developed from investigations of the following processing procedures:

1. Photomasks
2. Substrate Preparation
3. Metallization
4. Photoresist
5. Etching.

A.2 RESULTS

A.2.1 General Procedures

Clean room conditions were used for substrate preparation, metallization, and photolithographic pattern generation. To reduce surface aberrations to the absolute minimum, each procedural step of the overall process was divided into two or three procedural substeps. Visual inspection and thorough physical cleaning were implemented between each substep. The clean room used for substrate improvements is shown in Figure A-1.

A.2.2 Photomasks

Past LCR patterns were generated by a reliable photo-lithography technique used in the semiconductor industry since the 1950s. Basically, an accurately dimensioned set of drawings is generated by a mechanical designer for each azimuth and elevation plate. Three or more layouts using different scale factors are required for each reticle plate (e.g., liquid crystal cell, chip bonding pad, chip and signal electrical interconnect). These layouts require precise design since each must fit into a previously established area.

Figure A-1. Clean room used for substrate improvements.

The layouts are digitized on a Calma interactive graphics system to generate composite plots. Each composite plot is checked for errors, and corrections are incorporated immediately. Then a 10X master is generated on a Gerber photoplotter and checked for correct exposure and open or shorted lines. The 10X photophots are utilized to generate 1X chrome on glass photomasks which then are utilized to contact print the pattern onto a metallized glass reticle substrate.

Specialized vendors are used to obtain the 1X chrome photomasks. Several vendors have the potential to produce the high quality photomasks required on this program. Two vendors, Optronics and Micromask, were investigated further; Optronics was selected to produce the chrome photomasks.

Two (positive and negative) working sets of defect-free* chrome masks were obtained from Optronics to obtain high line yield; one mask is shown in Figure A-2. The masks were made from Hughes 10X masters and were anti-reflection coated, a technique successfully used in semiconductor wafer fabrication, to enhance contrast or reduce ghost images. Optronics was selected for continued needs on this program. The quality of photomasks obtained from Optronics is shown in Figure A-3.

Also Micromask could supply high quality chrome masks by photographic camera reduction and contact printing with Hughes 10X masters. Micromask also suggested two other approaches for making defect-free chrome masks (pattern generation and E-beam). They could pattern generate a chrome master from a Hughes Calma LCR library tape via converting to David Mann format with mask defects corrected by a Florod Masksaver. No working masks were procured from this source, because Optronics proved satisfactory.

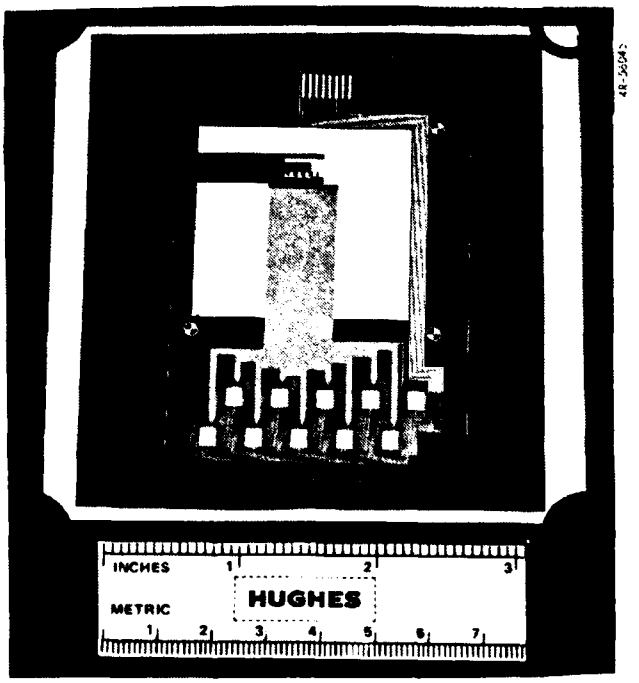
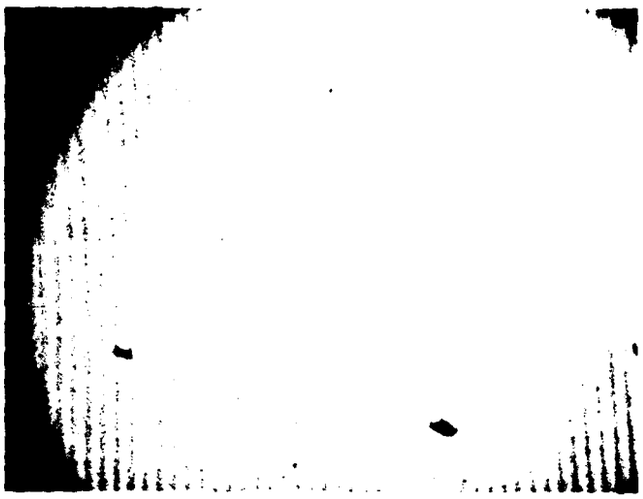


Figure A-2. High quality chrome photomask used to obtain 96 and 98 percent yield substrates.

*Defect-free means no open lines, no line-to-line shorts, or pinholes larger than one-third a line width.



a. 40X – even lines, no scratches.

b. 160X – high quality lines.

Figure A-3. Magnification of high quality chrome photomasks produced from Hughes 10X masters.

A.2.3 Substrate Preparation

Transparent conductive glass (indium tin oxide (ITO) coated soda lime glass) was purchased from Optical Coating Laboratory, Inc. (OCLI), Santa Rosa, CA. The manufacturer's designation of the coating was LCM 4000. The size of the glass was 11 x 16 inches and the coating had a conductivity of 10 to 30 ohms per square. Both 1/4 and 1/8 inch thick substrates were procured.

The stock sheet was scribed and broken into 2-1/2 x 3-1/2 inch substrates. Caution was used to ensure that the conductive coating was not scratched by the flaked-off glass chips. Then the cut sheets were waxed together into a block and ground to the desired dimensions. The figured substrates were then inspected under a microscope for pinholes and scratches in the reticle area.* Acceptable substrates were vapor degreased in TCE, isopropanol, and then sent for metallization.

A.2.4 Metallization

Outside the LC cell area, metallization over the ITO layer is necessary to enable bonding the electronic driver chips and to provide electrical interconnects. Three metal films (Ni-Cr-Au, Cr-Au, and Mo-Au) and three metallization machines (E-beam, RF sputter, and hot filament) were investigated. The best results were obtained with Ni-Cr-Au film using E-beam deposition.

Each metal film used approximately 150 Å of Ni-Cr or Cr with 5000 Å of Au; thickness was based on previous experience obtained in fabricating LCRs. Metallization was checked by testing adhesion with Scotch tape and pull strength of 1 mil Al wire bonds.

Using an Airco E-beam machine, 150 Å of Ni-Cr with 5000 Å of Au were deposited over the ITO layer, while keeping the substrate in circular motion for a uniform coating.

Initially, spikes in the film, which affect fine line resolution in the lithographic process, were observed in the E-beam evaporated Au film. The spikes were created by a fast deposition rate of Au during the deposition

*Pinholes and scratches in other areas were not critical, because they were covered with gold.

process and source contamination. When the rate was decreased and the source kept cleaner, no spikes were observed. Coatings produced by this method were smooth and dense. Samples passed the Scotch tape test and gave 6gs pull with wire bonds. Overall, this metallization system gave the most consistent results.

The same Ni-Cr-Au film was also deposited over ITO coated samples with a CVC hot-filament evaporator. Samples did not consistently pass the Scotch tape test, because of contamination of low vapor pressure materials in the vacuum chamber. An effort to clean the evaporator was unsatisfactory, and investigations of hot-filament metallization stopped.

RF sputtering was also investigated. Using a single target machine (a machine capable of holding only one metal target), approximately 120 Å of Cr (Ni-Cr target not available) was deposited first. Then the chamber was opened, the Cr target replaced, and approximately 5000-7600 Å Au deposited. Coatings produced by this method were smooth and more dense than the E-beam coatings. Samples passed the Scotch tape pull test and gave 8g pull with wire bonds. Although results appeared better, RF sputtering was not selected as an alternate to E-beam deposition because of the inconvenience of changing targets and chance of contamination.

A. 2. 5 Photoresist

Several photoresists evaluated for high resolution and high line yield included: Shipley positive resists AZ1350J and AZ1350B, Waycoat IC negative resist from Hunt Chemicals, and Riston negative film from Dupont. The Shipley AZ1350B was selected as the best photoresist for use on this program.

Riston (Dupont) film was somewhat difficult to laminate on the thick glass substrates. High resolution was also difficult to obtain because of the film thickness. This photoresist was not suitable for the LCR.

Waycoat negative IC resist (Hunt Chemicals) was spin coated on test substrates at 2000 rpm. The main drawbacks of this resist were the organic solvents required for development and less exposure latitude than the Shipley positive resists. This photoresist was also not suitable for the LCR.

Shipley AZ1305J, a positive resist, was spin coated on test substrates at 2000 rpm. An excessive buildup of photo-resist occurred around the

substrate perimeter due to high viscosity of the resist. The buildup was not eliminated by increasing the spin speed to 4000 rpm. The excessively thicker part of the photoresist could be removed by double exposure; i.e., covering the central area with an opaque mask and re-exposing to the UV light. Double exposure experiments were marginally successful, and the use of Shipley AZ1305J was not considered a sound choice for the LCR.

AZ1305B, being lower in viscosity, did not have a build-up problem. Because of low viscosity, however, the coating was thin, even at a preferred slow spin speed of 2000 rpm. The thin layer gave excellent line resolution but could not withstand the sputter etching process (sputter etching is preferable over wet chemical etching, to be described later). The problem was alleviated by a combination of chemical etching and sputter etching. Good fine lines with sharp definition were obtained with this approach, and Shipley AZ1305B was selected as the best available photoresist for the LCR. A set of procedures were established to apply Shipley AZ1305B to glass substrates and are briefly described next.

Before spin-coating, the substrate surface was rinsed with isopropanol while it was spinning. With this procedure the surface was cleaned, and it became easier to spread the photoresist. Next the photoresist was filtered through a 1 micron filter immediately before applying it to the substrate. Then the coated substrate was soft baked at 80°C for 30 minutes before exposure using a chrome mask. The photoresist spinner and exposure system are shown in Figure A-4. The chrome mask was aligned to the substrate to obtain exposure for the required delineation. The mask surface nearest the light source was flooded continually with dry nitrogen during exposure to prevent debris from settling on the mask and imposing defects onto the final pattern.

Exposed resist was developed with 50 percent AZ developer and 50 percent DI water for about 60 seconds with constant agitation in the direction of the fine lines, then rinsed for 60 seconds in DI water, and blown dry with hot nitrogen before being hand-baked in air at 100°C for 30 minutes. Finally, the developed pattern was inspected thoroughly for defects, before etching.

A side advantage of using a positive resist was that dust particles, lint, and particulate contamination in the photoresist showed up as line-to-line

Figure A-4. Photoresist spinner and exposure system.

shorts. Whereas, with a negative resist these contaminants showed up as an open line. Furthermore, a line short was much easier to correct than an open line.

A. 2. 6 Etching

Three etching techniques were studied: wet chemical, dry RF sputter, and a combination of wet chemical with dry RF sputter etching. The combination of wet chemical and dry RF sputter etching gave the best results.

Wet chemical etching tended to undercut the lines. This result was surprising because the ratio of line width (1.2 mils) to metallization thickness (0.02 mil) was sufficiently large to withstand some undercutting. The undercutting occurred while etching the ITO layer (rapid etching) and caused the Au to lift. In cases where the Au did not lift, uneven lines were observed. Wet chemical etching did not prove satisfactory for use with the LCR.

Dry RF sputter etching was solely dependent on the photoresist used. Best results were obtained with a thick photoresist layer, such as that encountered with Shipley AZ1305J. A thick photoresist layer withstood prolonged etching without deterioration, but gave edge build-up during application. In addition, the photoresist had to be vacuum baked for 1 hour before insertion in the MRC RF sputter etcher. This step was very important because without this prebake, the resist tended to outgass rapidly in high vacuum and generated small bubbles that spread into delineated areas to cause shorts. Because of the limited success with dry RF sputter etching, this approach was selected as an alternate to the preferred combination of wet chemical with dry RF sputter etching.

A combination of wet chemical etching with dry RF sputter etching was preferred for the Shipley AZ1305B photoresist. This approach was selected because of the thin photoresist layer that would not withstand prolonged sputter etching. The process established for the combination of wet chemical and RF sputter etching is briefly described next.

Only substrates with defect-free exposed lines (or nearly so) were selected for etching. Selected substrates were prebaked to eliminate possible bubbles forming in the photoresist during the later etching steps.

First, the selected and prebaked substrates were exposed to a gold etchant (J.E. Halma) until the exposed metallization was removed. Next, substrates were rinsed thoroughly and blown dry with nitrogen gas. Then the bottom of each substrate was greased (Apiezon M) to facilitate heat transfer and attached to a pallet. Substrates were RF sputter etched in a 12-inch MRC machine at 400 watts for 10 minutes with a low pressure inert (Ar) atmosphere. This process was repeated until the delineated areas were free of metal and ITO. After etching, the grease was removed with TCE (trichloro-ethylene) and the remaining photoresist rinsed off with Acetone. A modified Au etching process was used on test samples to open the transparent LCR active area.

A.2.7 Test Results

Four LCR azimuth substrates were prepared by cutting and ginding 1/4-inch thick ITO coated glass from OCLI. The ITO layer was overcoated with

Ni-Cr and Au by careful E-beam evaporation. The reticle pattern was generated on the metallized layer by using AZ1350B photoresist and a defect-free chrome mask supplied by Optronics. After development and hard baking, the substrate metallization was wet chemical etched. The last layer of ITO was sputter-etched in the 12-inch MRC sputter system. The photoresist was stripped after etching, and finished substrates were optically inspected and manually probed for shorts and opens in conductor lines. Results from processing without rework are given below:

Substrate Number	Number of Shorts	Lines Involved	Opens in LC Cell Area	Working Line Yield, percent
1	9	21	0	93
2	3	6	0	98
3	5	11	0	96
4	17	33	0	89

The line yield was computed on the basis of 301 lines. Two open lines were observed near one IC chip mounting pad (outside LC cell area) on Substrate 2. The opens were caused by a scratch in the photoresist that could have been repaired before etching. Most shorts could have been opened by a Masksaver.

Figure A-5 shows 96 and 98 percent working electrode line substrates. Magnification of the etched conductor lines on the 98 percent yield substrate are shown in Figure A-6 and may be compared to the similar chrome lines of Figure A-3.

A.3 SUBSTRATE REPAIR

Although not part of this contract, substrate repair was considered an important aspect of the substrate improvement task. For large substrate quantities, the probability of obtaining 100 percent yield appears low because of the possibilities of contamination in process materials and environment, plus human errors. At the same time, the probability of producing large quantities of 96 or 98 percent yield substrates appears high. Thus, it

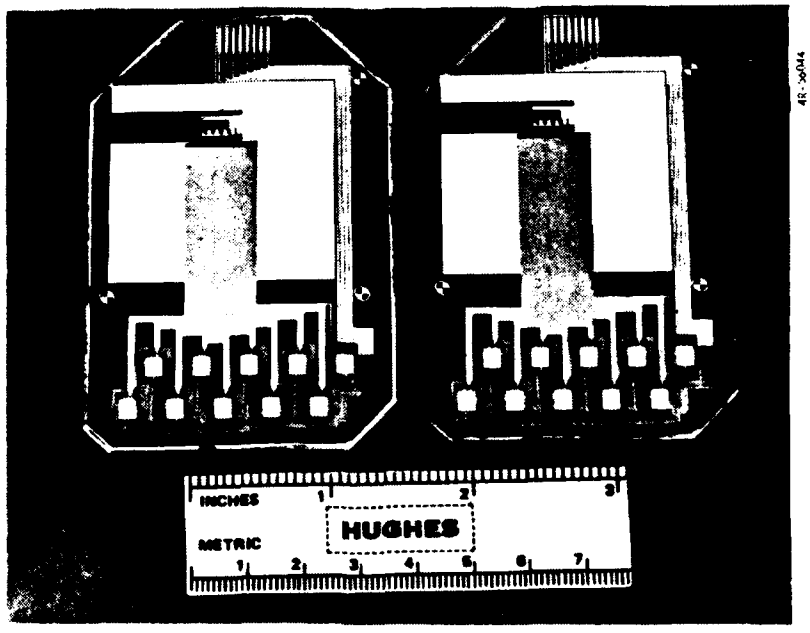
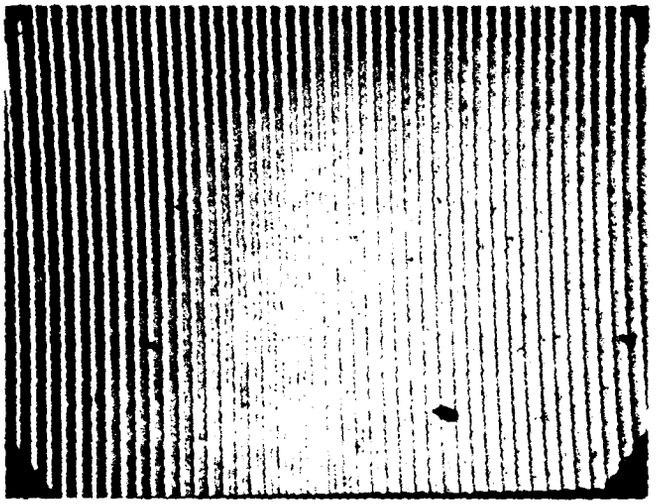


Figure A-5. 96 and 98 percent working electrode line substrates.

appears easier to correct the few defects on a large number of plates than to keep trying for 100 percent process yield. Capabilities for repairing few defective spots were investigated from a cost effective viewpoint.

Open lines in the active reticle area were not repairable because the conductors were ITO, and the scars from repair would cause defective liquid crystal molecular alignment. Fortunately, open lines were rarely encountered with the positive photoresist. Open conductors near the chip mounting areas were repaired by standard wire bonding; i.e., 1 mil Al wire was used to bridge an open in a 2 mil wide line.

Three methods were tested for repairing shorts, namely electric arc, YAG laser, and pulsed Xenon laser. The pulsed Xenon laser proved the best approach for substrate repair. An electric arc using the LCR substrate as one electrode to burn off the shorted spot was tested. The size of the burning area was not easy to control, and the burned scar was objectional. A diamond stylus was also useful in scribing open shorts, but scratches were left in the glass that were considered undesirable for shock loading. A Korad laser system (YAG laser, Mode KY3), designed for resistor trimming, was



a. 40X – etched substrate lines.

b. 160X – etched substrate lines.

Figure A-6. Magnification of etched conductor lines on 98 percent yield substrate.

useful for opening shorts between lines with more than 0.001 inch spacing. The major drawback for this laser was that the beam size was not easily adjusted and the beam proved difficult to focus.

A "Masksaver" station, which used a xenon laser and was manufactured by Florod Corp., Hawthorne, CA., was more versatile and viable for the repair work. It could be fine focused, and the beam size adjusted freely to match the defect configurations. It also had a spot marker for the laser so that the operator could pinpoint the defective spot. Using this laser repair technique, substrates with process defects were finished with 100 percent line yield.

Using the "Masksaver" station, the time required to spot defects, zap them open, reclean the substrates, and retest for line yield was considerably less than the time required to process another batch of substrates for 100 percent yield. Therefore, the ability to salvage plates with few defects was judged highly cost effective.

A.4 CONCLUSIONS

The overall objective of this task was to achieve 100 percent working electrode lines with approximately 500 lines per inch density of liquid crystal reticle glass substrate plates. To achieve the objective of this task, techniques were developed from investigations of the process sets, namely photomasks, substrate preparation, metallization, photoresist, and etching.

A major effort to improve the quality of photomasks contributed considerably to the success of this task. The establishment of strict cleaning procedures for substrate preparation improved yield by reducing particle contamination. The use of careful E-beam metallization virtually eliminated voids and metal spikes, a contributor to poor line yield. Proper selection and application of photoresist was, possibly, the most important step in processing substrates. By properly exposing the photoresist and with visual inspection before etching, the line yield was improved. Finally, once the process was understood and the parameters defined, few defects were observed from etching. From the techniques developed on this task, plates of 96 and 98 percent working electrode lines were fabricated without repair.

Although not part of the contract, substrate repair was investigated from a cost effective view point. The time required to repair few defects (2 to 4 percent) on a substrate was judged considerably less than the time required to process a new substrate and attempt 100 percent process yield. Using pulsed Xenon laser techniques developed to repair defects, plates of 100 percent working line yield were fabricated.

APPENDIX B
LIQUID CRYSTAL SEAL DEVELOPMENT TASK

B.1 AIMS AND OBJECTIVES

The overall objective of this task was to define parameters and develop a seal that was chemically compatible with the reticle manufacturing process. To ascertain these parameters, tests were required on various peripheral sealant candidates, methods of filling the cell, sealing the fill hole, LC alignment, and bulk LC material – all to ensure long operational and storage lifetime. A sufficient quantity of material was required to allow parallel testing of heating, cooling and voltage effects on sealed cells. Finally life-tests were required on sample cells to prove sealant compatibility with the reticle manufacturing process and long lifetime.

B.2 RESULTS

B.2.1 Liquid Crystal Material

The first requirement was to synthesize more LC for testing. The Hughes proprietary LC-R9 material is a multi-component mixture, which is doped for conductivity. Each component was synthesized and recrystallized to obtain 99.8 percent purity, determined with an analytical liquid chromatograph. For a few components, however, recrystallization was not sufficient to achieve the high level of purity desired. For these samples, a preparative liquid chromatograph was used to separate the desired material for similar chemical structure impurities.

B.2.2 Liquid Crystal Sealant

To meet the objective of this task, the peripheral seal around the liquid crystal cell that comprises the active optical display must fulfill a variety of needs. It must contain the liquid crystal fluid over a wide temperature range and allow for the differential expansion coefficients between the glass substrates, the seal, and the fluid. It must be formed to allow filling the cell

after the seal is made. Means must be provided for plugging the filler hole(s). The seal must protect the liquid crystal material form moisture, oxygen, and other contaminants throughout the required life of the device. And, of course, the seal itself must not contaminate the liquid crystal. The desired life of the device is 10 years, of which several hundred to several thousand hours may be operating time.

Three types of peripheral sealants (thermoplastics, glass frits, and dry film preforms) were investigated for use in the LCR. The thermoplastics were unsatisfactory because of reaction with the LC material or poor screen print characteristics. The glass frit was not compatible with established LCR fabrication techniques because of the high (500°C) temperatures and extensive changes required for Hughes proprietary LC-R9 material. Excellent results were achieved with a dry film preform sealant, Abelfilm 539; it also satisfied the task objectives. Results from the three types of peripheral sealant are described in the remainder of this subsection.

Thermoplastic Sealants. The thermoplastic sealants were applied by a screen print process similar to that used in commercial art. Basically, the sealant was screen printed around both sides of each electrode plate with 0.3 to 0.5 mil thickness using 325 mesh screen and zero emulsion thickness. Then, the printed sealant was baked at +125°C for up to 1 hour to "cure" the polymer and drive out any solvents. Next, LC material (LC-R9) was dropped on one electrode plate and covered with the other electrode plate to form a captive cell. Finally, each cell was clamped together and heated (>100°C) for a few minutes. The advantages of these procedures were simplicity of sealing and no fill hole.

A thermoplastic sealant TPA-82 (American Liquid Crystal Chemical Co.) was evaluated first because it appeared to have the most potential and was widely used in industry. TPA 82 was easily screen printed on test cells and required a 120°C temperature for sealing. Test cells functioned well electrically. However, storage at 80°C for about 1 day showed creeping of the sealant into the viewing area and misorientation of molecular alignments along the perimeter because of interaction between sealant and LC. On further investigation, TPA 82 was found to have a softening point below 120°C

and to contain plasticizer. Destruction of the alignment was attributed to the plasticizer.

Other screen print thermoplastics investigated were Eponol 53-L-32 (Shell Oil), Methylon 75202 (General Electric), 642-1 and 681-14 (Ablestik Laboratories). All sealants were difficult to screen print, and the solvent odor was highly objectionable. Two thermoplastics, AL 600 and MC 600 (Mermid), obtained from the Hughes Adhesive Laboratory were also tested but showed poor screen printing characteristics, and the seal was much too brittle. No thermoplastic sealant was judged suitable for use in the LCR, and all work on these sealants was stopped.

Glass Frit Sealants. The glass frit sealing process investigated was quite similar to the thermoplastics sealing process. A paste of glass beads was screened onto one of the glass sheets in the form of a ring seal. After glazing, the second plate was put into place, and the assembly heated to fuse the glass into a solid seal. The major differences were that the frit processing temperature was significantly higher (500°C), and a fill hole was required. Even though a glass frit seal with a soldered fill hole was considered a hermetic seal, the high temperature process impacted fabrication of an LCR to a greater degree.

As reported earlier, the Ni-Cr-Au or Cr-Au metallization was unsuitable for high temperature sealing because of interdiffusion between metal layers. Although encouraging results were obtained from some initial work on a Mo-Au metallization system, a change (factor of two) in the resistivity of the ITO occurred during heating and had to be controlled by limiting the time at high temperature. In addition, the Hughes proprietary LC-R9 material was impacted by a glass frit seal because the dopant and surface alignment requirements were not compatible.

A sizeable expanded effort was needed to further investigate the compatibility of using a glass frit sealant in the present LCR manufacturing process required and was considered beyond the scope of this contract. At this same time, successful sealing was achieved with a dry film preform, and work on the glass frit seal was stopped.

Dry Film Sealant. The dry film peripheral seal is formed from a thin piece of material (usually Mylar), which is coated on both sides with a film of epoxy. The total thickness is accurately controlled, and the epoxy is specially formulated for use with LC materials. The composite sheet is cut to shape and clamped in place between the two pieces of glass as shown in Figure B-1. Then the whole assembly is brought to a curing temperature (approximately 125°C), and the seal is formed.

Ablefilm 539 (Ablestick Laboratories) was the only dry film peripheral sealant investigated. Its test was strongly recommended by Hughes personnel who had experience with this material as well as experience with LC devices.

Hughes successfully applied Ablefilm 539 to early watch LCDs, while the first use in an LCR occurred on a previous Army contract (DAAK-70-78-C-0023). During that contract, an Ablefilm sealed LCR was subjected to shock and vibration tests with no damage. A sealed cell was also temperature cycled from -40 to +51°C with no leaks.

Extensive testing was used to determine the applicability of Ablefilm 539 for LCRs. Initially several cells were constructed of both type I and type II material, then filled with Hughes proprietary LC-R9. Some cells were stored at +80°C, while others were stored at -15°C. The type I cells deteriorated after 200 hours at +80°C, while the type II cells did not deteriorate. Additional cells were constructed of both types of material (type I and type II), then filled with Hughes proprietary LC-R9, and the tests rerun. Again the type I material failed in +80°C storage. Little evidence was uncovered to indicate the cause of the type I cells failure in +80°C storage.

Results from the life tests (subsection B.2.4) have been very encouraging because sealed cells using Ablefilm 539, Type II, material have now surpassed several thousand hours without deterioration. Two additional tests were conducted on cells fabricated with Ablefilm seals. One cell was cooled with liquid nitrogen in an attempt to break the Ablefilm seal. The glass cracked, and the seal remained intact. A second cell was soaked for 1 day in boiling water and 6 additional days in room temperature water. At no time did the sealant show signs of weakening.

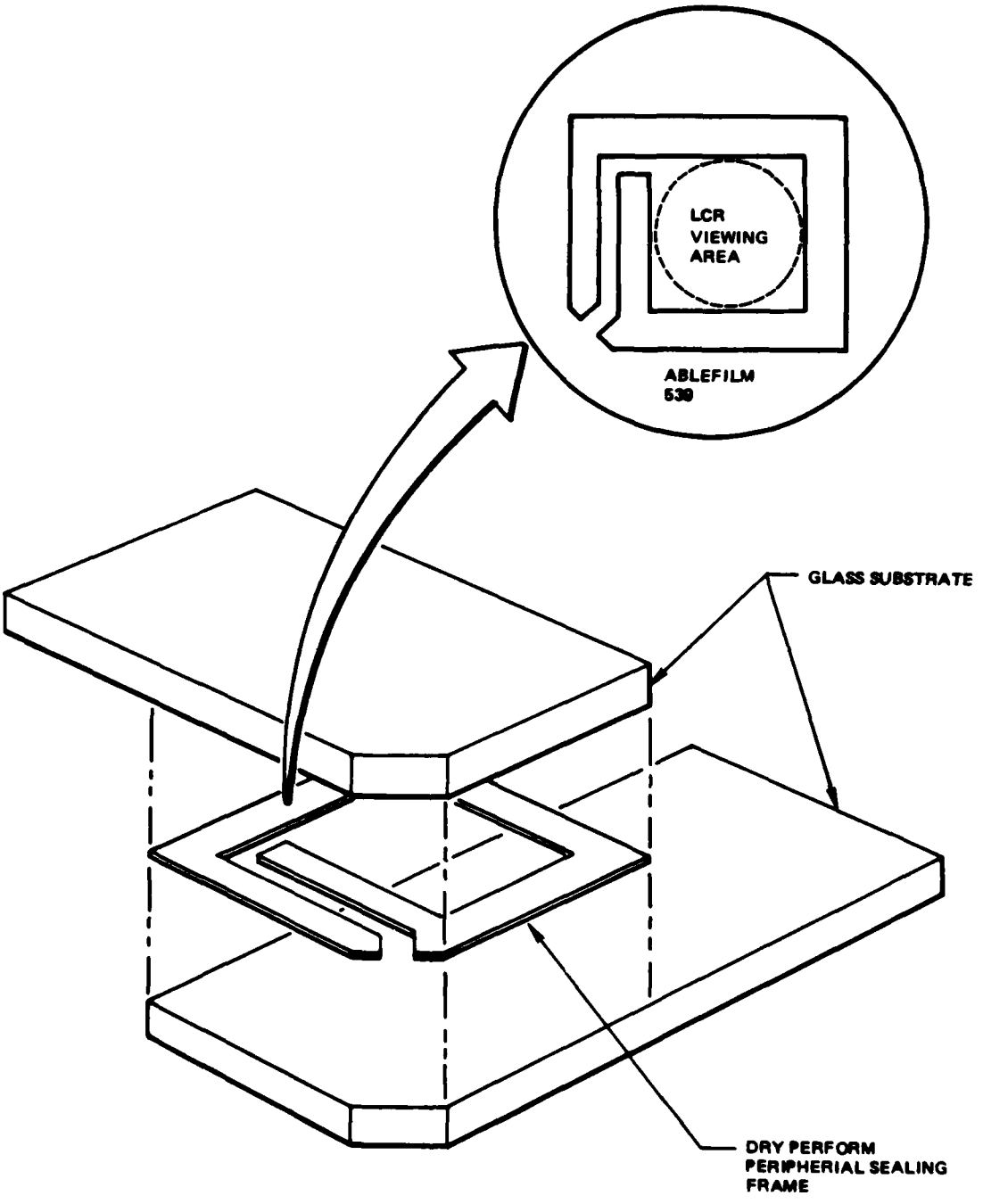


Figure B-1. Liquid crystal cell assembly using dry film peripheral sealant with fill channel.

B.2.3 Fill Hole and Fill Hole Sealant

The method of filling the LCR cell and plugging the fill hole(s) were considered important subtasks to prevent leaks. Two techniques were investigated to fill an LCR. The one-hole edge fill method was preferred over a two-hole method.

Two fill holes were investigated for use on the LCR because some commercial devices still use the technique. The technique does not require special fill apparatus (vacuum system) because the LC material is forced through the first hole, while air exhausts through the second hole. Problems with forcing the LC material into the cell, plus a much higher probability of leakage (two holes) forced the abandonment of this technique.

Early commercial LC displays, including the first LCRs, used a hole drilled through glass for filling in a vacuum chamber. Commercial LC devices, including the LCR, later went to a more economical edge fill method that utilized the LC peripheral sealant (see Figure B-7) and a vacuum chamber. Briefly, the LCR assembly is placed in a vacuum chamber and, after evacuation, dipped into a pool of LC material. At first capillary action starts filling the cell, but as the vacuum is slowly released, LC material is sucked into the remaining evacuated cell area. Alternately, to conserve LC material, the fill hole can be oriented so that a drop of LC material covers the opening, then as the vacuum is slowly released the drop is sucked into the evacuated cell.

Three approaches were investigated to plug the fill hole(s): indium, epoxy, and solder. An epoxy plug performed satisfactorily and was preferred over the other two approaches.

Indium is soft, easily forced into a small glass hole, and does not react with most LC materials. Early LCRs used an indium plug for a drilled glass fill hole. However, greater contraction of the indium at -40°C, during temperature cycling, created leakage and required epoxy reinforcement. Thus the value of an indium plug at low temperatures was useless; therefore, this approach was judged not suitable for use on the LCR.

A solder seal technique studied, relied on Ni-Cr-Au being evaporated around the fill hole and solder applied to seal the hole. Although this seal was more expensive than epoxies, it was also considered a hermetic

seal. One major drawback was the necessity to vacuum deposit Ni-Cr-Au around the LCR fill hole. The solder seal technique to seal a fill hole was not tested on LCR sample cells because of the success achieved with the use of epoxies.

Epoxy fill hole sealants were used on some past LCR and on all test cells constructed for this contract. Two Ablestik sealants, 224-1 and 408-3, performed satisfactorily as an edge-sealant. Both were single component room temperature curing epoxies. The difference between the two was in the working life, 20 minutes for the former and 2 hours for the latter. The sealed cells showed no leakage and interaction with the LC after temperature cyclings and storage at 80°C for an extended length of time.

B.2.4 Life Tests

The majority of AC type cells were prepared with bulk electrodes, i.e., continuous electrodes covering the LC cell area. Three major life tests were selected for sample cells: +80°C storage, -17°C storage, and continuous AC voltage drive (100 Hz). Hot storage at +80°C was selected for an extra margin of safety over the +71°C maximum storage temperature specified in a tank environment. The -17°C temperature was selected as the point where bulk crystallization of Hughes proprietary LC-R9 probably would occur. This temperature was more critical than storage at -40°C (or lower). Finally, a continuous AC voltage drive test was selected to study long term alignment conditions in the LC cell.

The heating lifetest was monitored by observing alignment changes in the sealed cells after storage in an oven set at 80°C. Each cell was observed between crossed polarizers, which proved to be a very sensitive test. After more than 6000 hours, the LC alignment had no observable changes.

The freezing life test was monitored the same way as the heating test with storage at -17°C. Again, after more than 6000 hours, no change in alignment or LC crystallization was observed in cells between crossed polarizers.

Two methods were used to test the effect of voltage on the LC alignment test cells. In one case, continuous bulk electrodes were used in sealed cells. In the second case, a small test reticle was made with fixed lines addressed by a continuous voltage. In each case, a 20-volt (100 Hz) squarewave signal was generated with the same type of chip used in the reticle. For the continuous bulk electrode cells, no change in alignment was observed after more than 6000 hours. A residual line was observed (without polarizers) in the reticle-type cell, however, after 1550 hours with voltage removed. This line was only noted in one cell, and it appeared that the alignment agent on the surface was rubbed off on the edges of the indium-tin oxide lines.

B.3 CONCLUSIONS

The overall objective of this task was to define parameters and to develop a seal that was chemically compatible with the reticle manufacturing process. To achieve this objective, three subtasks were defined and investigated: the peripheral LC cell sealant, LC cell fill methods, and the LC fill hole sealant.

The first requirement for this task was to synthesize additional Hughes proprietary LC-R9 materials. Each component was synthesized and recrystallized to obtain 99.8 percent purity, determined with an analytical liquid chromatograph.

Of the three LC peripheral sealing schemes investigated, the dry film sealant with Ablefilm 539 (type II) proved the best approach. The sealant gave excellent results and satisfied the task objective. At no time during tests did the Ablefilm sealant show signs of weakening or reacting with the Hughes proprietary LC-R9 material. Ablefilm 539 (type II) was inexpensive, simple to use and directly compatible with the present LCR manufacturing process.

The method of filling the LCR cell and plugging the fill hole(s) were considered important subtasks to prevent leaks. Of the techniques studied to fill an LC cell, only the one-hole edge fill method was compatible with the reticle manufacturing process. Means of plugging the fill hole were also investigated. Of the schemes studied, epoxy sealants, Ablestik 224-1 or Epoxy Technology 408-3, performed satisfactorily.

Life tests were performed with the Hughes proprietary LC-R9 material using cells constructed of Ablefilm 539 (Type II) with a one-hole edge fill and epoxy fill hole sealant. Tests at +80°and -17°C have surpassed 7000 hours without cell deterioration. Cells with bulk electrodes and continuous AC voltage have surpassed 6200 hours at +25°C without alignment change.

APPENDIX C
ELECTRONICS SEAL DEVELOPMENT TASKS

C.1 AIMS AND OBJECTIVES

The main objective of this task was to develop an environmental seal for the electronics required to address and drive individual azimuth and elevation reticle lines. Considerations were given to the selection of a seal compatible with the reticle manufacturing process that would not create opens or shorts of individual reticle lines.

C.2 RESULTS

C.2.1 Considerations and Approach to Electronics Protection

Currently the CMOS electronic driver ships are designed to mount on each LCR glass substrate. To maintain the desired reticle reliability, the driver chips controlling reticle operation must be protected from damage caused by either mishandling or environmental exposure. Mishandling can result in mechanical damage, such as the accidental destruction of wire bonds or devices, and is best avoided by encasing the electronics in a protective package. Environmental damage occurs primarily when moisture in the system allows corrosion to occur, this problem can be controlled by minimizing the opportunities for moisture to be introduced. Thus, it is particularly important to have a knowledge of the moisture-induced failure mechanisms for the CMOS technology used in the electronic driver chips.[1]

The primary moisture failure mechanisms of concern to the CMOS devices used on the LCR were

1. Electrical parameter changes caused by motion of charge in or on oxides
2. Aluminum metal corrosion (wire bonds, chip inter-connections).

Increased gate input current, higher gate threshold voltage and increased leakage current are the more important electrical parameters readily changed

[1] L. J. Gallace, H. L. Pujol, and G. L. Schnable, "Reliability of CMOS Integrated Circuits," Computer, 11, No. 10, October 1978, pp 6-13.

by charge motion. Both chlorine and the more corrosive sodium ion migration cause electrical parameter changes. Water vapor encountered in a moderately harsh military environment readily contains these ions. Chlorine ions attack aluminum used in integrated circuits for interconnect metallization and wire bonds. For instance, in a matter of a few days after exposure to moisture containing chlorine, the aluminum contacts cannot pass electrical signals. To protect the chip aluminum metallization, inorganic passivation materials are very effective in reducing the possibility of aluminum corrosion. Gold wire is used to replace aluminum wire for bonding, but at increased cost and lower wire rigidity.

Three approaches were investigated for use on the LCR: epoxy encapsulation, protective coatings, and conventional hybrid solder sealing. The selected approach was conventional hybrid solder sealing with new packaging schemes to protect the electronic driver chips. Hybrid solder sealing approach used a mature reliable technology to ensure good electronics seals. An electronics module with all azimuth or elevation driver chips was used to devise two packaging concepts: (1) rigid-flex cabling to physically separate the LC cell from the electronics module or (2) bonding the electronics module to the LC cell.

Epoxy encapsulation was ruled out because of poor repairability, non-compatible curing temperature, unsuitable outgassing materials, and lack of solid data on moisture protection.

Initially protective coatings were investigated on a Hughes-funded IR&D program. Coatings were investigated because they promised to shield the electronic driver chips from particle or moisture contamination (mechanical protection necessary to prevent mishandling). On this contract, protective coatings were investigated further and were found to be incompatible with the present LCR manufacturing process because of poor repairability, a need for multiple coatings, and an aging process that created microcracks in the coatings. The microcracks were judged to leave the electronic chip particularly susceptible to moisture contamination.

The three approaches are discussed next. Electronics protection, repairability, and applicability to the present LCR manufacturing processes are discussed for each approach.

C.2.2 Epoxy Encapsulation

The use of epoxy was considered to obtain a hermetic seal primarily because the circuitry did not have to be coated before encapsulation. Other advantages considered were low process cost, good resistance to shock and vibration, and mechanically strong package not requiring a cover.

Four potential problems associated with epoxy encapsulation of the reticle driver chips were studied:

1. Curing
2. Outgassing
3. Repair
4. Moisture Protection.

No adequate solution to these potential problems was found.

Epoxy compounds that cured well and did not outgass below 80°C were difficult to identify. Outgassing materials were particularly important so as not to attack and destroy the CMOS devices. An effort to investigate epoxy encapsulation materials for use on the LCR was beyond the scope of this contract.

The combination of high humidity levels (>85 percent) and elevated temperature (>100°C) is known to accelerate moisture-induced failure mechanisms in epoxy encapsulated devices. Advances were made in recent years to improve moisture resistance epoxies for semiconductor packaging, but years of testing are required.

Repair of epoxy encapsulated electronics was the last iten of concern. Selective etching techniques (chemicals) were difficult if not impossible. Sawing or cutting was not particularly attractive on the reticle. Heating an epoxy above the curing point was another method considered, but temperatures were well above 80°C. Thus, all factors considered, the disadvantages of using epoxy encapsulation on the LCR to protect the driver chips outweighed the advantages.

C.2.3 Protective Coatings

Requirements for a protective coating are given below:

1. To prevent moisture from contacting either the chip surface or chip-to-substrate interconnection wires
2. To not influence chip electrical performance
3. To be simply re-applied after chip or wire repair
4. To be compatible with the present LCR manufacturing process.

Two materials and three coating conditions were investigated on the Hughes IR&D program. The two materials were silicon nitride and parylene "C". The three coating conditions were silicon nitride, parylene "C", and silicon nitride over parylene "C". These coatings had moisture vapor transmission rates that are lower than other materials used in electronic packaging.[2, 3]

The silicon nitride (Si_3N_4) process was a low-temperature photochemical deposition developed by the Hughes Technology Support Division. The temperature of the sample during deposition was never higher than 100°C (65°C minimum), and the technique used ultraviolet light to excite the mixture of silanehydrazine. A mercury vapor resonance-arc source was used to sensitize the molecules with 2537Å radiation. To achieve sufficient radiation of the gas phase, the system was saturated with mercury vapor. The excited mercury atom collides with the chemicals in the system to generate free radicals. These initiate the chain reactions that lead to the final Si_3N_4 product. A uniform layer of 800 to 1500Å thick was deposited on exposed surfaces. Repairs of bonds were performed without removing the coating.

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[2] "Low Temperature Deposition of Silicon Nitride Passivation Layers," Hughes Contract No. F33615-76-C-5081, R&D with AFML, 15 February 1977.

[3] S. M. Lee, J. J. Licaci, "Reliability of Parylene Films," NASA/Electronic Research Center, Anaheim, CA, NDA

Parylene "C" was produced by vapor-phase deposition and polymerization of para-xylylene or its substituted derivatives. Molecular weight was approximately 50,000. Unlike dip or spray coating, condensation coating did not run off or sag. It was not "line of sight" as in vapor metalizing; the vapor coated evenly over edge, points and internal areas. With parylene, the object to be covered remained at or near room temperature and eliminated all risks of thermal damage.

Parylene "C" over silicon nitride was deposited in the same manner as described for each material separately. No special cleaning or handling procedures were needed. Adhesion of the parylene to silicon nitride was generally better than adhesion of the parylenes over bare alumina. To initially evaluate the coatings, 1 x 1 inch HAC PAC test packages were prepared. These contained moisture-sensitive chips and transistors mounted on etched thin film patterns of gold metallized alumina. These moisture chips were made by Panametrics and allowed in MIL-STD-883B, Method 1018. With these chips, the amount of moisture trapped inside a sealed package can be known without having to destroy the package.[4] 2N2222 transistor chips,* were attached by the silver-filled conductive epoxy, Abelbond 606-2. The moisture chips were attached with non-corrosive epoxy Abelfilm 550. The substrates were bonded in the HAC PACs with Scotchcast 281.

Two sets of test packages were coated with silicon nitride, parylene "C" and combination of silicon nitride over parylene "C". Control packages were also prepared with the coated samples (hermetic packages, plus uncoated and consealed packages). The first set of samples (except hermitic control) were protected mechanically with a silicon rubber gasket and clamped metal lid. The second set of samples (except hermetic control) used on epoxy bonded metal lid.

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[4] M. G. Kovac, et al, "A New Moisture Sensor for in-situ Monitoring of Sealed Packages," Inter. Reliability Physics Symposium, 13 April 1977, Las Vegas, NV.

*Hughes proprietary CMOS chips were not available during IR&D program.

By using the SEM (Scanning Electron Microscope) and EDAX (Energy Dispersive X-Ray Analyzer) when necessary, composition and uniformity of each coating were determined, both before and after environmental tests. Some silicon nitride coated samples showed chlorine ions trapped in the coating, caused by the solvent used to clean the deposition chamber. When the cleaning solvent was changed, the deposited layer closely followed the contour of the sample and was free of nodules. EDAX analysis showed complete absence of contaminants. The parylene "C" coated samples were uniform, but adhesion to the alumina, silicon and gold was marginal, i.e., the coating could be peeled off once a free edge was grasped with a pair of tweezers. The coated samples of parylene "C" over silicon nitride were uniform and free of nodules or bubbles.

The samples were tested according to MIL-STD-810C, Method 507-1, which is the minimum DOD requirement for land-based electronic instrumentation. The test consisted of cycling the samples in 95 percent relative humidity for five cycles (one cycle lasts 24 hours) through the temperature excursion 25 to 60°C. The first set of samples (11 packages) was run for five cycles, as required by the MIL-STD, and tested. The second set of samples (eight packages) was run for 15 cycles with electrical testing every five cycles. All electrical and humidity readings were obtained within 2 hours of removal from the moisture chamber.

The initial test results performed on the Hughes IR&D program are summarized below. Changes in moisture at the silicon chip's surface are given in PPM of water.

Compared to the hermetic package (300 ppm), mechanically protected samples coated with the parylene/Si_3N_4 combination provided the best protection against moisture penetration (2000 ppm). MIL-STD-883, Method 5008 defines an acceptable moisture level in hybrid packages of 6000 ppm at one atmosphere pressure. Thus the package ambient cannot reach a dew point at a temperature above 0°C.

The silicon nitride coating (2000-5000 ppm) was nearly as effective as the combination coating, whereas only the parylene alone was unsatisfactory (10K to 20K ppm moisture). As expected, the uncoated sample had a very high moisture content (>100K ppm).

The second set of packages was subjected to three times the required number of cycles specified in MIL-STD-810C. A slight improvement in protection was provided by the method of sealing the lid to the package. In this experiment, the clamp and lid assembly was replaced with a lid attached to the base by the Ablefilm 550 epoxy.

The electrical data taken showed that epoxy sealing of the second set of samples resulted in less moisture buildup during environmental exposure than occurred in the lid clamp samples of the first set. The damage to the uncoated samples increased after 3 weeks of exposure, as expected.

For this contract, a plan was formulated to rerun the coating tests using CMOS devices on glass substrates, which were bonded to 14-pin Tekform dip packages. The package scheme was compatible with automatic test equipment. The reasons for this plan were that the previously used packages did not simulate glass reticle plates and CMOS devices were judged to be much more sensitive to moisture than bipolar devices. In addition, the silicon nitride coating was to be applied at temperatures below 100°C, i.e., 75°C.

After 32 sample packages were prepared, several events occurred that completely stopped the tests. First, previously unknown evidence was introduced about an undesirable long-term aging effect in parylene "C" coatings. Coatings of parylene "C" held at room temperature for more than 3 years show that cracking of the material had occurred. Second, experiments indicated process problems associated with silicon nitride deposition at +75°C. Problems also occurred concerning the repeatability of coatings and were considered analogous to sudden loss of yield on a semiconductor wafer line. Finally, experiments to remove the coating, repair a chip, and recoat were not successful.

The coating process was not economical to apply, and the question of process yield was not answered. Thus, the economics plus unsatisfactory test results led to dropping the use of a coating to protect the electronic driver chips on the LCR.

C.2.4 Conventional Hybrid Solder Sealing

Conventional solder sealing is of interest because the technique is widely used in military hybrids to provide mechanical and hermetic protection in a single operation. The procedure consists of metallizing an electronic chip layout on a ceramic substrate, complete with a border for sealing. A Kovar ring this is soldered in place on the substrate border. Next, die attachment and electronic functional tests are completed. Before sealing, the whole assembly is cleaned and a lid soldered on the ring to complete the package. For severe environments, lids with a small hole are used for sealing. The purpose is to pull out the air and refill with a dry inert gas before plugging the small hole. At this point, the whole assembly is gas leak-checked to ensure a long-term hermetic seal.

Conventional hybrid solder sealing techniques cannot be used directly on the LCR glass substrates because of the possibility of ruining the LC cells and cracking the glass substrate from the high temperatures. To use conventional hybrid solder sealing, a new packaging scheme was required to:

1. Overcome the disadvantages of the other electronic sealing methods studied and utilize reliable conventional hybrid sealing techniques.
2. Produce LCR assemblies in the quantities required and at reasonable cost to the government.

Two concepts were studied and described below. Both offer a solid approach to low-cost reliable reticle assemblies with the unique ability to independently fabricate and test high-line yield LC cells and sealed electronics modules.

The first concept uses rigid-flex cabling (RFC) to physically separate the LC cell and electronics module(s) to maximize producibility and maintainability. RFC is a proven and reliable technology for militare components suppliers. Several major connector and cable manufacturers are now supplying RFC to the military.

Using the RFC concept, LCR packaging can be modified to fit the needs of each requirement without the need to redesign either the reticle plates or electronics module. Production costs are certainly lower for a large lot of one flexible design rather than for smaller lots of several rigid designs.

A second concept being studied does not physically separate the LC cell from the sealed electronics module. In this case, the sealed electronics module using either hybrid or LSI technology is bonded and wired to a high line yield working LC cell. This approach has the same potential advantages of lower costs, higher overall yield, and improved reliability as the above device that uses RFC. This design is somewhat more rigid in its mechanical structure but has the advantage of not requiring cables.

Both concepts make use of proven, reliable electronic hybrid or LSI technology to ensure good seals. They appear to be applicable to most of the currently deployed fire control systems.

An LCR electronics module designed with standard catalog parts and conventional hybrid sealing technology is shown in Figure C-1. The RFC concept incorporated into a LCR package is shown in Figure C-2; a bonded electronics module incorporated into a LCR package is shown in Figure C-3.

C.3 CONCLUSIONS

The main objective of this task was to develop an environmental seal for the electronics to address and drive individual azimuth and elevation lines. To achieve this objective, a sealing scheme was required that was compatible with the reticle manufacturing process while not creating opens or shorts of individual reticle lines.

Three electronics sealing schemes were rigorously investigated, and the conventional hybrid solder sealing was selected as the best approach. Convenventional hybrid solder sealing uses proven and reliable technology to ensure good seals; but to produce LCR assemblies in the quantities required and at reasonable cost to the government, innovative packaging design was also required. The ability to independently fabricate and test a high line yield LC cell and sealed electronics module resulted in low cost reliable reticle assemblies.

Two packaging concepts were devised that use the same electronics module. The first concept used rigid-flex cabling to physically separate the high line yield LC cell and electronics module. Using the RFC concept, LCR packaging can be modified to fit the needs of each requirement without redesigning the reticle plates. The second concept did not physically

separate the LC cell from the sealed electronics. In this case, the sealed electronics module is bonded and wired to a high line yield LC cell. This design is somewhat more rigid in its mechanical structure but has the advantage of not requiring cables.

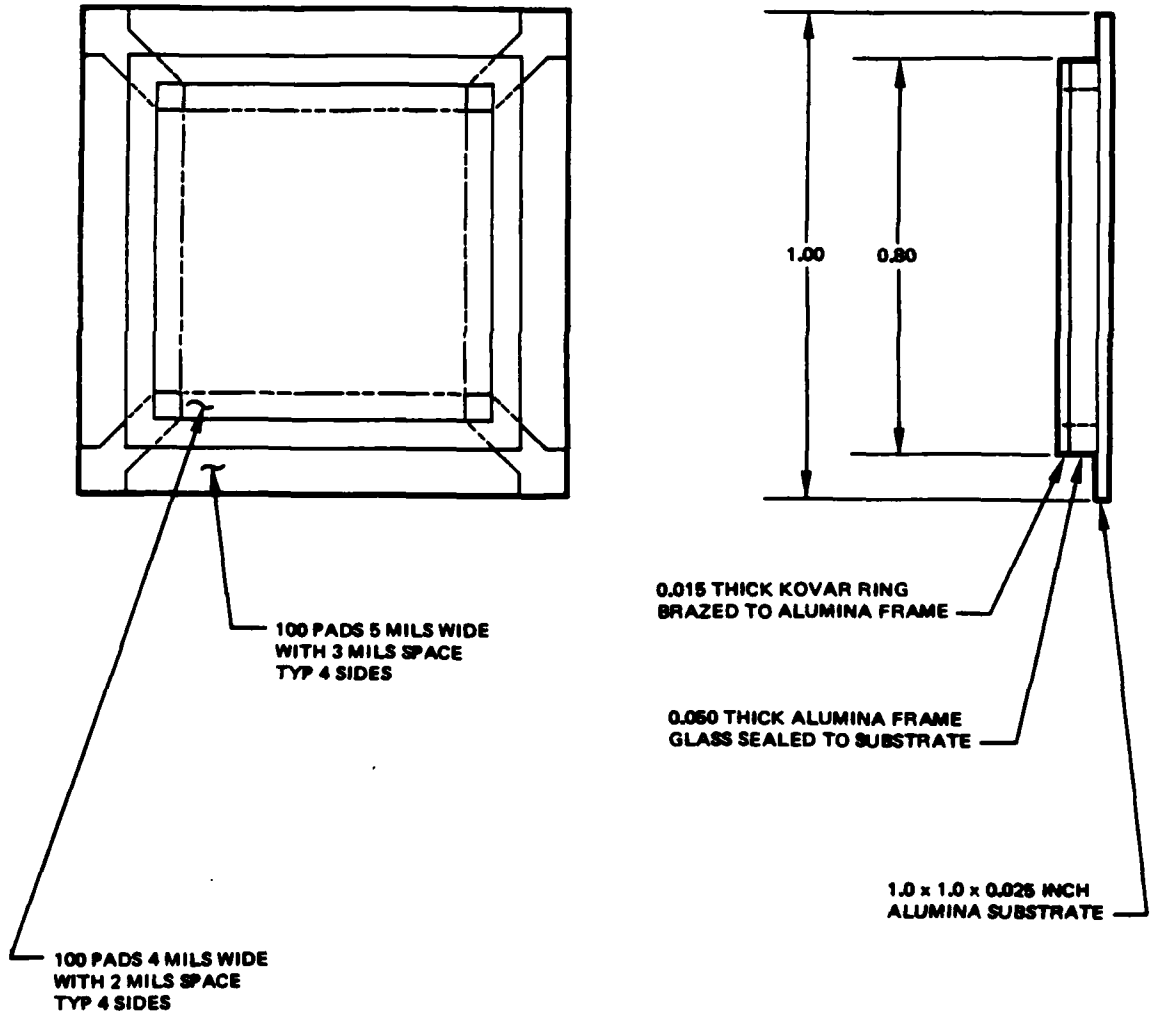


Figure C-1. Electronic module.

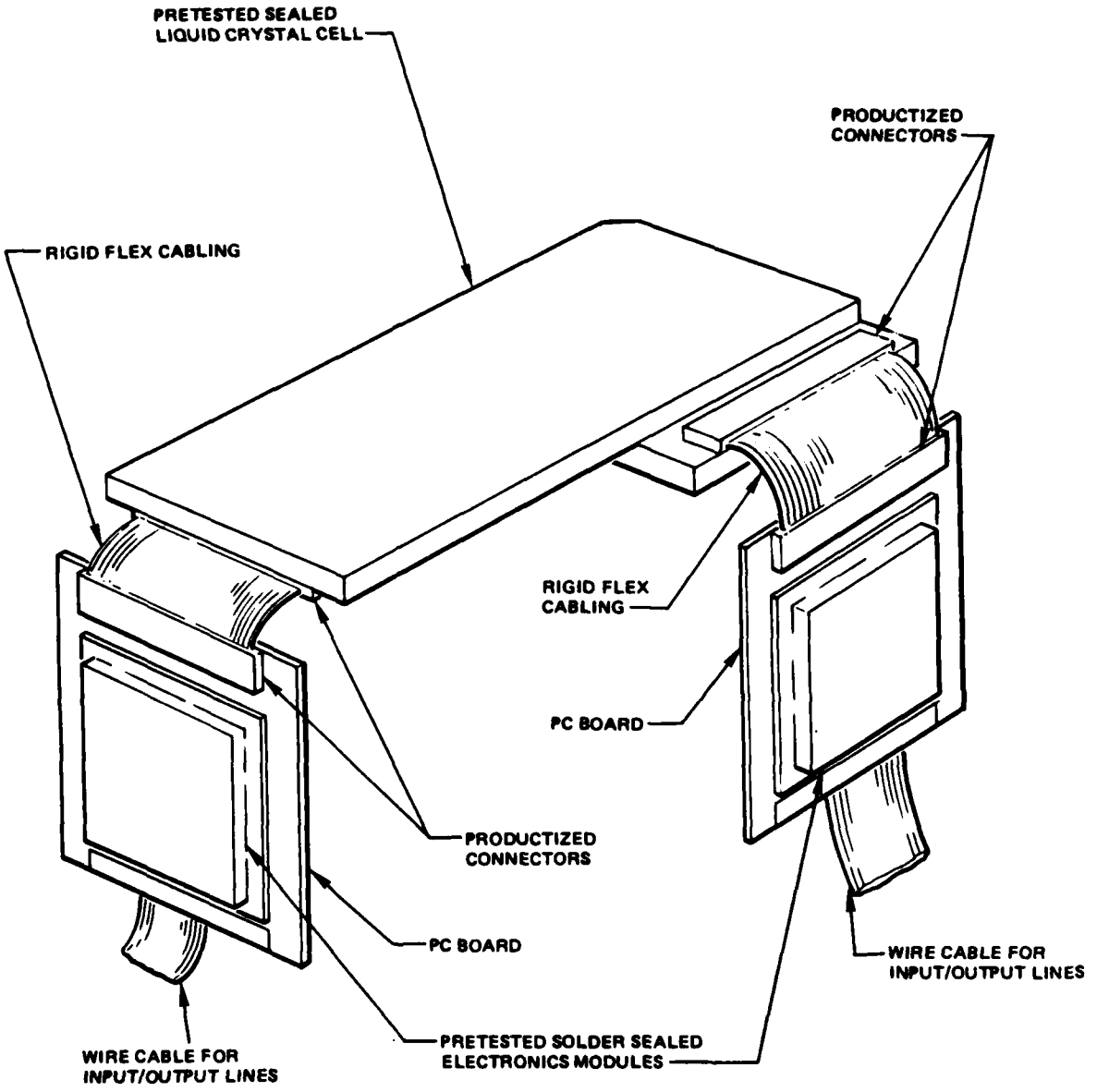


Figure C-2. Pretested electronics modules connected to pretested liquid crystal cell via rigid flex cabling.

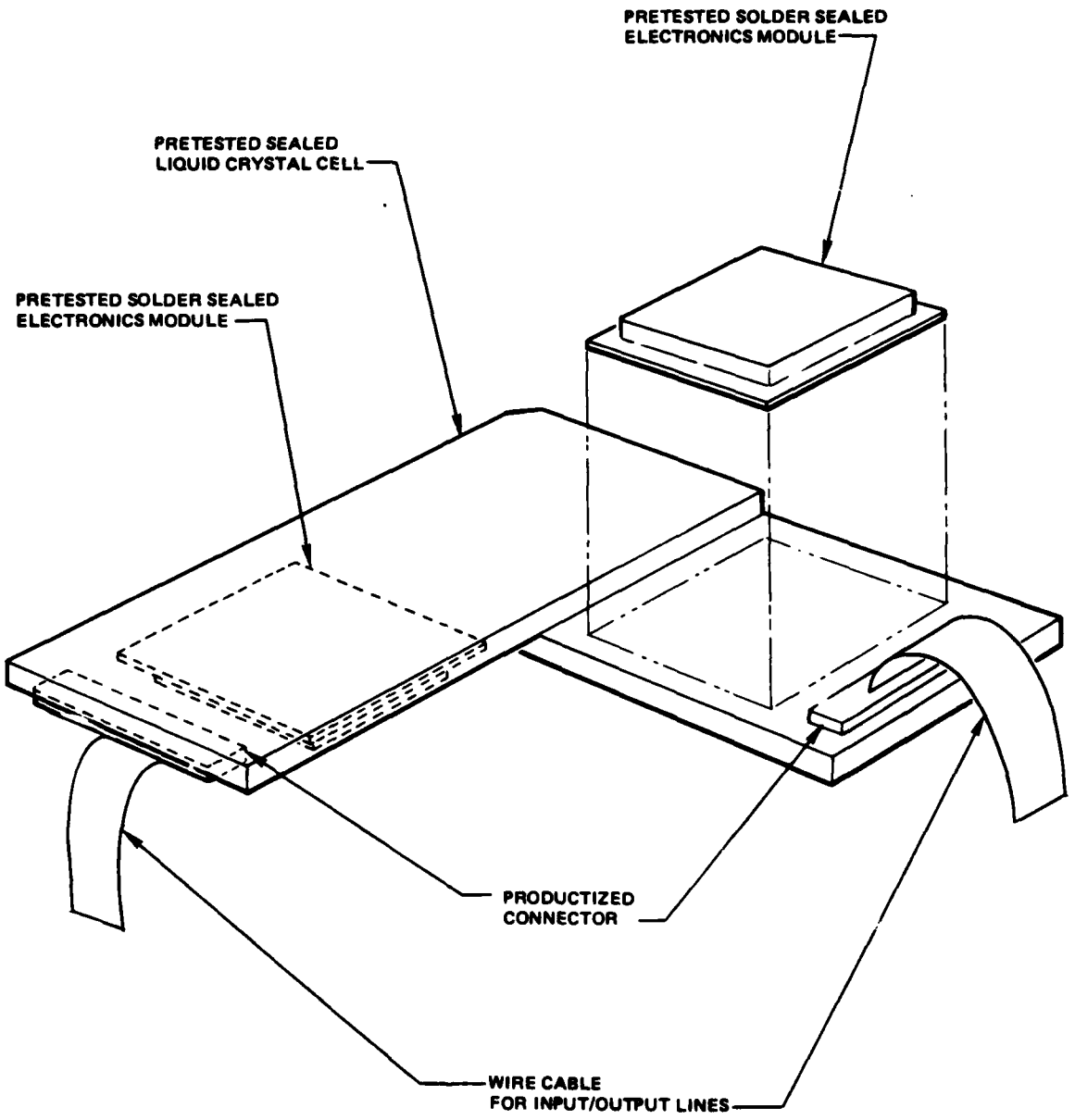
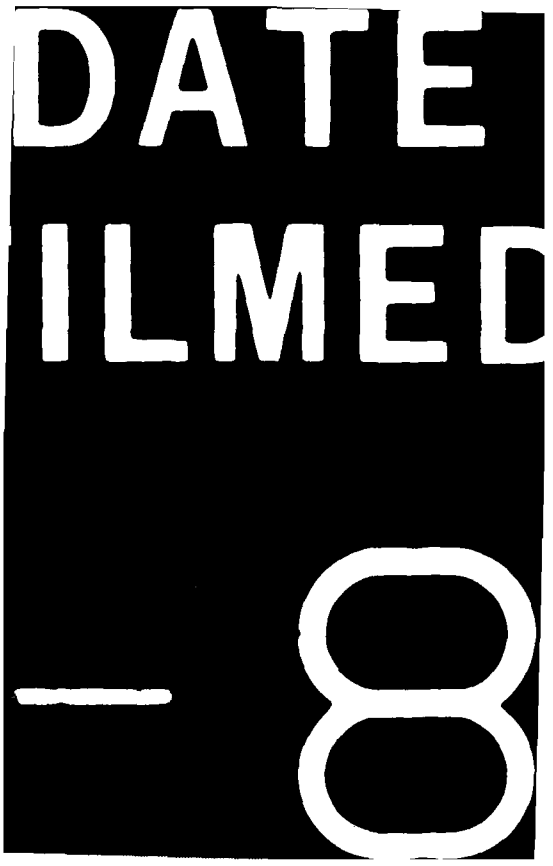


Figure C-3. Pretested electronics modules bonded to pretested liquid crystal cell.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